Aquatic Inventory of Nadgee Lake, Nadgee River and Merrica River Estuaries

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Nadgee Lake, Nadgee River and Merrica River in far south NSW are in NSW's only coastal wilderness and have no human habitation; Nadgee Lake and Nadgee River have no public roads in their entire catchments. They are as close to pristine as exists for NSW estuaries. During the period November 2008 to March 2009, data were collected on physical and chemical properties of the water, bathymetry, phytoplankton assemblages, pelagic chlorophyll, fish assemblages, estuarine macrophytes, sediment infauna and zooplankton in Nadgee Lake and River; and physical and chemical properties of the water and pelagic chlorophyll in Merrica River. The sampling plan was based on current conceptual understanding of the function of intermittently open estuaries in south-eastern NSW. It was intended to provide a basic representation of the ecological processes and types of organisms found in the estuaries.

There was no submerged aquatic vegetation found in any of the estuaries. Fish assemblages were relatively diverse for unvegetated intermittent estuaries, but were composed of common estuarine fish. Salinity in Nadgee Lake was about 19 psu and in the River varied between 20 and 33 psu. Concentrations of ammonia and chlorophyll in Nadgee Lake were far greater than expected for this type of estuary. Nadgee River and Merrica River were closer to expectations. These data comprise what is, to our knowledge, the first comprehensive collection of data on the aquatic ecosystems of these estuaries and represent a valuable base-line of data for pristine intermittent estuaries in NSW.

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INTRODUCTION

The consistent monitoring of estuary condition in NSW is in its infancy. The first state-wide monitoring program, focussed on water column productivity (using chlorophyll as a surrogate), water clarity, fish population structure and extent of aquatic vegetation, commenced in NSW in 2008 (Roper et al. 2010). An important aspect of this type of monitoring program is having an appropriate benchmark against which to judge estuary condition. The National Water Quality Management Strategy (NWQMS; ANZECC 2000) suggests using data from reference sites to establish trigger values or reference conditions as a basis for comparison. If trigger values are exceeded, ANCECC (2000) suggests further investigation to determine if intervention is required to improve water quality. Reference sites (in the context of NWQMS) are defined as minimally impacted. There are, however, few data available from minimally impacted systems as there has been little incentive or funding available for research in unimpacted areas. Most research has focussed on impacted estuaries near large population centres (Scanes et al. 2007).

This paper provides a preliminary inventory of the aquatic environment in the estuaries of the Merrica River, Nadgee River and Nadgee Lake in far southern NSW. These estuaries are believed to be among the least disturbed estuaries in NSW (Evans 2003). The catchments of all three estuaries now lie wholly within the Nadgee Nature Reserve (Evans 2003) and thus are protected from most forms of modern human disturbance. To the knowledge of the

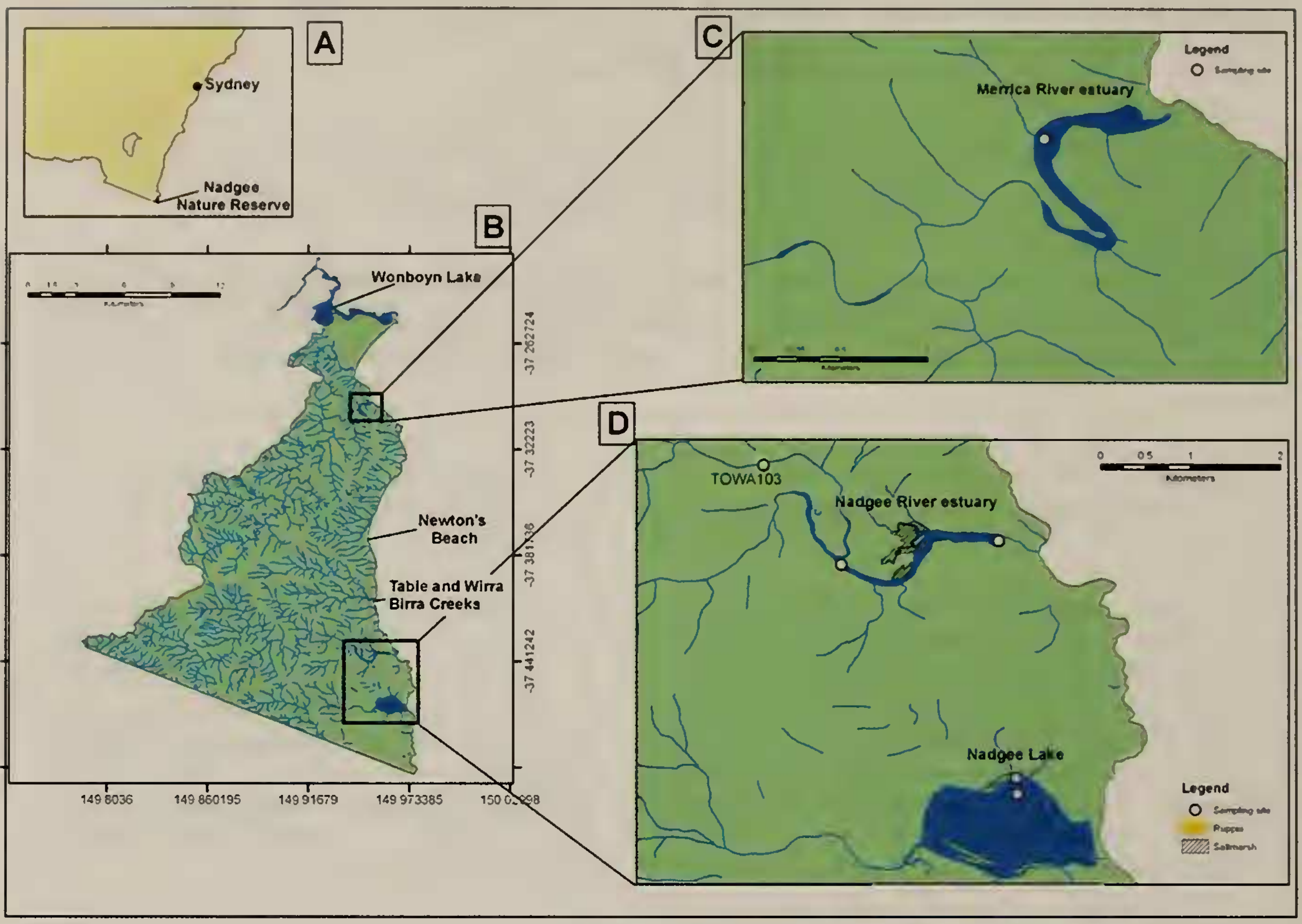

Figure 1 Location of Nadgee Nature Reserve (A, B) and sampling sites in Merrica River (lower) (C), Nadgee River freshwater (TOWA103) and upper and lower estuary, and Nadgee Lake (D). Locations of macrophytes are as shown in Williams et al. (2006) and do not reflect occurrence in 2008.

authors, there has been no previous assessment of the aquatic ecology of these systems (Evans 2003).

Nadgee Nature Reserve is located on the far south coast of NSW between Wonboyn Lake and the Victorian border (Fig. 1). The major part of the area, 11,430 ha, was initially gazetted as a faunal reserve in1957 under the Fauna Protection Act. It was dedicated as a Nature Reserve in 1967 and included the entire catchments of Merrica River, Nadgee Lake and Nadgee River. That part of Nadgee Nature Reserve south of Newtons Beach was declared the Nadgee Wilderness in 1994. The wilderness was increased in 1997 by the inclusion of the whole of the Merrica River catchment (Evans 2003), except for a narrow road corridor and infrastructure at the Merrica River.

Historical European land use in the Nadgee area commenced around the 1860's and included stock agistment and as a stock route to the south. Two graziers moved to the area in the 1890's, living near the lower Nadgee River flats and lower Table River. They used the area, mainly the heaths, for rough grazing. In 1916 a road was constructed across the Merrica River to Nadgee River flat and land was cleared to build a farm. This farm was worked until the lease was terminated shortly before creation of the reserve in 1957 (Evans 2003). Whilst there are reports of low intensity grazing and some farming around the estuaries up until the 1960s, there are no records of any settlement or disturbance in the catchment of Nadgee Lake. Current public access is restricted to pedestrian and boat access. Access is by permit and only a total of 30 persons are allowed in the combined Nadgee Wilderness and Howe Wilderness Area (Victoria). Researchers may obtain permission to drive vehicles on an established fire track as far as Nadgee River, but access to the River estuary and Lake is by foot from that point (special conditions apply).

There are estuaries on the Merrica River, Wirra Birra Creek, Table Creek, Nadgee River and at Nadgee Lake. The estuaries are deepened Pleistocene valleys which are now filled with sand, apart from the Merrica River estuary which lies in a gorge (Evans 2003). Merrica River and the two Nadgee estuaries were classified by Roy et al. (2001) as intermittently closed (Group IV) saline lagoons (Type 8). We have

Table 1 Estuary and catchment characteristics for main estuaries in Nadgee Nature Reserve. * Table Creek was not classified by Roy et al. (2001). # from Dela-Cruz and Scanes (2009). CA:SA is the ratio of catchment area to surface area of estuary. Class is the classification as defined by Roy et al. (2001).

	Class	Catchment Area (km^2)	Estuary Surface Area (km^2)	CA: SA	Total Suspended# Sediment Load ($t.yr^{-1}$)	Total Phosphorus# Load ($t.yr^{-1}$)	Total Nitrogen# Load ($t.yr^{-1}$)
MERRICA RIVER	IV 8 A	60.54	0.12	504	104.15	0.28	5.01
TABLE CREEK	IV 8 *	17.29	0.06	288	27.31	0.08	1.31
NADGEE RIVER	IV 8 D	58.80	0.27	217	240.44	0.65	11.58
NADGEE LAKE	IV 8 B	13.70	1.20	11	22.23	0.06	1.07

extended this classification to Table Creek. The Nadgee Lake estuary was described as semi-mature, Nadgee River as mature and Merrica as youthful (Table 1). Intermittent saline lagoons account for 49% of the 131 major NSW estuaries classified by Roy et al. (2001). Of those, 42% are semi-mature, 20 are mature and 31 % intermediate.

The Plan of Management (Evans 2003) provides a comprehensive collation of the available information on the Nadgee Nature Reserve. The paucity of information on the aquatic ecology of the reserve (freshwater and estuarine) is evident, there are no quantitative estuarine data referred to in the Plan of Management. Subsequently, only two sources of quantitative information on aquatic ecology could be found. A biological (AUSRIVAS macroinvertebrate) assessment of the main freshwater streams (Turak et al. 1998) concluded that "AUSRIVAS outputs from the sites sampled at Nadgee Nature reserve in 1997 and 98 … suggest that the three streams, Merrica River, Nadgee River and Table Creek have macroinvertebrate communities similar to those in reference sites sampled during the development of AUSRIVAS" (Turak 1998). Williams et al. (2006) provides maps of estuarine aquatic vegetation in Nadgee Lake and Nadgee River. These maps were produced from aerial photography with limited ground-truthing (due to the access issues) and showed saltmarsh around Nadgee River and submerged aquatic macrophytes (presumed to be *Ruppia megacarpa*) in Nadgee Lake (Figure 1). The "Development Plan" which was the basis for establishment of the Nature Reserve (NPWS 1975) refers to a "dense growth of algae and spermatophytes in lagoon bed proper" for Nadgee Lake. Presumably the spermatophyte referred to is *Ruppia megacarpa*, but that is not confirmed anywhere in the document. The Plan of Management (Evans 2003) indicated the presence of estuarine wetland and saltmarsh on the Nadgee River estuary, noting that it was dominated by rushes, sedges and swamp paperbark (*Melaleuca ericifolia*). Since the Plan of Management, there has been some desk-top work characterising all NSW estuaries, including the Nadgee estuaries. Dela-Cruz and Scanes (2009) collated catchment dimensions and modelled nutrient loads for all NSW estuaries. These data (Table 1) show that Merrica River, Table Creek and Nadgee River have relatively large catchments in comparison to the size of the estuary, meaning that they will be likely to fully displace estuary water after significant rain. Nadgee Lake, however, has a small catchment in comparison to estuary size, meaning that there will be little runoff which will, in most cases, be trapped by the estuary (Roper et al. 2010). Roper et al. (2010) used a ratio of modelled "pre-European" nutrient runoff to nutrient run-off under current landuse as a measure of catchment disturbance. All the Nadgee Nature Reserve estuaries had a ratio of 1 (i.e. no change), putting them in the pristine category.

Nadgee Lake has been used by black swans as moulting lagoon on an annual basis since at least 1972, supporting populations in excess of 300 birds which feed extensively on submerged vegetation (Evans 2003, L Evan pers. comm., P Catling pers. comm.). NPWS (1975) also refers to numerous swans on Nadgee Lake. Early reports (back to 1880, see NPWS 1975) refer to Nadgee Lake as "Saltwater Lake" so it can be assumed that it has been saline for at least 130 years.

Commencing in early November 2008, sampling was undertaken to establish a preliminary set of aquatic data for Nadgee River estuary and Nadgee Lake. This is, to our knowledge, the first comprehensive collection of data on the aquatic ecosystems of these estuaries. These data were supplemented by further collections in Nadgee Lake and River in early January, February and March 2009; and from Merrica River 6 times between December 2008 and March 2009.

Access limitations, which require most equipment and samples to be carried on foot for up to 16 kilometres constrains the type of work that can be undertaken. The sampling plan that was implemented was based on current conceptual understanding of the function of intermittently open estuaries in south-eastern NSW (Scanes et al. 2007, Dela-Cruz and Scanes 2009, Roper et al. 2010). It was intended to provide a basic representation of the ecological processes and types of organisms found in the estuaries and to complement estuarine monitoring occurring under the current NSW State Monitoring Evaluation and Report Strategy. For Nadgee Lake and River, data were initially collected on physical and chemical properties of the water, bathymetry, phytoplankton assemblages, pelagic chlorophyll, fish assemblages, estuarine macrophytes, benthic sediment chlorophyll, sediment infauna and submerged light climate. Data for Merrica River were confined to physical and chemical properties of the water and pelagic chlorophyll. These data will provide a baseline for comparison with other south eastern Australian estuaries.

METHODS

Nadgee Lake and Nadgee River will be referred to as the Lake and the River in following sections. At the time of the first sampling trip (10-12 Nov 2008), both the Lake and River estuaries were closed.

In the Lake and the River, data collection was stratified into two zones, shallow waters (< 1m deep) and deeper waters (>1 m deep). Data collection in deeper waters, and bathymetric profiles, were done from inflatable canoes which were carried to the sampling sites. In the Lake, data on water properties and biological samples were collected from two sites in each of the shallow and deep zones (Table 2). The River estuary was sub-divided into a marine-sediment dominated lower region and a riverine-sediment dominated upper region. There was no shallow zone in the upper region. The types of samples collected at each site at each time, are provided in Table 2 and are described in full below.

A - Physical and Chemical Properties of the water

Sampling during the first trip (10-12 Nov 2008) differed slightly from subsequent trips. During trip 1 the following procedures were followed. A calibrated Hydrolab® Water Quality Sonde was used to measure salinity, temperature, dissolved oxygen, pH, and turbidity at the water surface and at 0.5 m intervals to just above the bottom. At each site, a single integrated water sample was taken from the top 1m of the water column by slowly plunging a pre-rinsed bottle and allowing it to fill on the way down. The water samples were sub-sampled for the analysis of nutrients. Samples were either left unfiltered (total nutrients) or immediately filtered through a 0.45 µm filter (dissolved nutrients). Concentrations of nutrients were determined by flow-injection absorption spectrometry according to standard methods (APHA, AWWA and WPCF 1989). A sample for the determination of colour was filtered through 0.20 µm filter. Estimates of the dissolved colour or gilvin concentration were calculated as $g_{440} = 2.303 * A/0.01m^{-1}$ where A was the measured absorbance of the filtered water sample at 440 nm in a 1 cm cuvette (adapted from Heinermann et al. 1990).

Calibrated water quality data loggers (Yeokal® Model 612) were placed in 1.0 - 2.0 m of water in each estuary and data logged every 15 min. The loggers were collected approx. 4 weeks later.

Immediately after collection calibrations were checked to determine sensor drift during deployment.

During subsequent trips (see Table 2), data on physical properties of water were collected using a YSI® Model 6820V2-S multiprobe fitted with a fluorometric chlorophyll probe and a turbidity probe, as well as temperature and salinity probes. In each estuary, the probe was placed in the water over the side of a canoe and data were logged for five minutes while the canoe was allowed to drift. The reported result is a mean of the logged data and represents a zone in the estuary rather than a single point. Water samples were collected from the top 1m using an integrated sampler.

B - Depth

A simple unit which combines depth measurement (approx. accuracy 0.05 m) and GPS (approx. accuracy 1-2 m) was paddled around the water body, including transects from deep to shallow and along the thalweg (River). The unit logs depth and position continuously. In Nadgee Lake in January 2009, a bench mark was established on a fixed structure (tree) to allow calibration of relative depth of the Lake to a standard datum. In June 2010, the height of the Lake and berm above Australian Height Datum (AHD) was estimated using a hand-held surveyor's level and an estimate of sea level. This was then back-calculated to the benchmark to estimate lake level (AHD) at the time of sampling.

Table 2 Sampling sites and types of samples taken in each estuary in: A: physical and chemical properties of the water; B: depth; C: phytoplankton assemblages; D: pelagic chlorophyll; E: estuarine macrophytes; F: fish assemblages; G: sediment infauna;

Zone	Date	Time	Sample Types
Nadgee River Estuary			
Lower Shallow	12/11/08	am/noon	A, B, C, D, E, G
Lower Deep	12/11/08	am/noon	A, B, C, D, E, F, G
Upper Deep	10/11/08	pm	A, B, C, D, E, F
Upper Deep	12/01/09	am	A,D
Upper Deep	24/02/09	am	A,D
Upper Deep	13/03/09	am	A,D
Nadgee Lake			
Zone	Date	Time	Sample Types
Site 1 Shallow	11/11/08	am/noon	A, B, C, D, E, F, G
Site 1 Deep	11/11/08	am/noon	A, B, C, D, E, F, G
Site 2 Shallow	11/11/08	am/noon	E, F, G
Site 2 Deep	11/11/08	am/noon	E, F, G
Site 1,2 Shallow	12/01/09	am	A,C,D
Site 1,2 Shallow	24/02/09	am	A,C,D
Site 1,2 Shallow	13/03/09	am	A,D,
Merrica River			
Zone	Date	Time	Sample Types
Site 1 Deep	02/12/08	am/noon	A,D
Site 1 Deep	13/01/09	am/noon	A,D
Site 1 Deep	03/02/09	am/noon	A,D
Site 1 Deep	25/02/09	am/noon	A,D
Site 1 Deep	17/03/09	am/noon	A,D

C - Phytoplankton assemblages

To determine the dominant algal species present in Nadgee Lake, water samples were taken from the top 1m of the water column with a 1m integrated sampling tube. One litre of the sample was fixed with Lugol's iodine solution (5% v/v) and 500 ml was kept cool and dark to generate live cultures. When blooms were obvious in Nadgee Lake (Nov 08 , Jan, Feb 09) live material was sent to CSIRO laboratories and University of Tasmania in Hobart where it was taken into culture. Samples of the culture were inspected by light microscopy and subjected to pigment analysis to determine dominant types of algae.

D - Pelagic chlorophyll

Three replicate sub-samples (250 ml) from the integrated water samples were filtered through GF-60 filters under low vacuum pressure and the concentrations of chlorophyll retained on the filters was determined by fluoro-spectrometry after acetone extraction. In addition, a YSI ® Model 6820V2-S multiprobe fitted with a fluorometric chlorophyll probe was used to determine in-situ chlorophyll concentrations.

E - Estuarine macrophytes

Ground-truthing of the existing aquatic vegetation was done by observing the types of vegetation present. Observations were made directly or by deploying a small grapple to entangle attached vegetation from the estuary floor and bring it to the surface. Inspections of the intertidal strand line were made to identify the types of vegetation present in the estuary. Samples of salt marsh and any submerged plants found were retained for expert identification.

F - Fish assemblages

Inshore fish assemblages were sampled by 3 replicate shots with a small seine net (12 mm stretched mesh seine net with a 20 m headline, a 2 m drop and a cod-end) at each site (lower Nadgee River was not sampled by seine because the net could not be transported to the site). Each replicate net haul was done to form a U-shape that covered approximately 100 m^2. The ends were drawn together so that the sample was collected in the cod-end. By its nature, this net will only catch small or slow-moving fish. It therefore does not provide a measure of the total fish diversity at a site. To partially address this issue, fish assemblages in deeper water (< 3m) were sampled by three multi-panel monofilament gill nets at each site. Nets were set at a 45° angle from the shore and at a depth of no more than 3 m. Each gill net was left out for 30 - 45 min of fishing time. All fish captured (by both methods) were placed into a bucket to keep them alive while being identified counted and measured (fork-length), then released alive.

G - Sediment infauna

Replicate samples of sediment from depths between 0.5 m and 1.0 m were collected using a 90 mm diameter core. The sediment was passed through 1 mm and 0.5 mm sieves and the matter retained was fixed. The biota in the samples were later identified and enumerated.

H - Zooplankton

Unquantified tows with a conical plankton net (63 µm mesh) were made in August 2009 to sample the dominant zooplankton. Samples were washed from the nets into small vial, fixed with 70% v/v ethanol and examined under a Leica Wild M8 stereomicroscope at a magnification of x 25 or x 50. In a separate quantitative sampling, 10L samples of water (n=4) were collected from the Lake in June 2010 for enumeration of zooplankton. Zooplankton specimens were concentrated by filtering through a 63-µm mesh netting and fixed with 70% v/v ethanol. A 1-mL wide-mouth automatic pipette and Sedgewick-Rafter counting cell were used for subsampling and counting of zooplankton. Zooplankton specimens were examined and identified under a Leica Diaplan compound microscope at a magnification of x 100, with an image analysis system consisting of Leica DFC480 digital camera and Leica IM Version 4.0 digital imaging software (Leica Microsystems, Germany). The prime taxonomic literature used was Yamaji (1984) and Suthers et al. (2009).

Freshwater

Freshwater sampling was done at the same site sampled by Turak (1998) - Nadgee River ford; 37° 25' 48.40" 149° 56' 17.93" (TOWA103). Physical properties and nutrient concentrations (by method A above) were determined and macro-invertebrate samples were collected, sorted and analysed according to standard NSW AUSRIVAS methods (Turak and Waddell 2001).

RESULTS

Nadgee Lake

Observations

In November 2008, the lake was closed and the beach berm was wide (c.a. 40 m at narrowest point). Anecdotal information (L Evans pers. comm., P Catling pers. comm.) suggests that the lake had been closed for > 2 years in November 2008. No swans were sighted, they had been absent for at least 6 months.

Bathymetry

The lake is a simple basin, which gradually slopes to a maximum depth of 4.5 m approximately 150 m off the shore when the lake is at its highest levels. The central basin is very flat and of consistent depth. Calculations based on a relationship between salinity and lake surface height and a survey of the berm in June 2010 (DECCW, unpubl. data) indicate that in November 08, Nadgee Lake surface was at about + 0.7 m AHD (Table 3 A) and the berm was at least + 1.7 m AHD. When closed and full, the water surface area of the Lake is estimated at 120 ha, with an estimated volume of 3.86 ML.

Physical and chemical properties of the water

Surface salinity in primary samples ranged between 17.9 and 19.7 psu (Table 3 A), the variation being due to rainfall and evaporation. Salinity did not vary between surface and bottom in November 2008. Data from the submerged logger showed salinity remained constant at about 19 from 10 November until 23 November 2008, when there has heavy rainfall in the catchment (40 mm on 23, 24 November, 70 mm 29 November). After this, salinity fell to 14 psu, briefly rose again and then stabilised at 13 psu until 22 December. This plateau at 13 psu does not match other measurements and is questioned. By 12 January 2009, salinity had risen to 17.9.

Surface water temperature reached a summer

Table 3 Physical characteristics of surface waters, estimated water surface levels (Nadgee Lake) or entrance state (Nadgee River) and mean (SE) pelagic chlorophyll concentrations . Colour is inferred from the absorbance of light at 440 nm, data are adjusted to 1 cm light path. SpCond – specific conductivity at 25°C, DO dissolved oxygen; DO %sat – percentage of theoretical saturation of dissolved oxygen at ambient temperature. "NSW Trigger" is the trigger value (sensu ANZECC 2000) for chlorophyll and turbidity in lagoon estuaries calculated by Roper et al. (2010). "Median Other" are median values for 4 other NSW minimally impacted lagoons (Termeil Lake, Meroo Lake, Brou Lake, Wallagoot Lake) sampled between 2008 and 2010 (n = 60) and "80th Other" is the 80th percentile value calculated from the same data (DECCW unpublished data).

A Nadgee Lake

	Salinity (psu)	Temp (°C)	Turbidity (ntu)	pH	Lake Height (AHD)	Chlorophyll (µg.L^{-1})	Colour g m^{-1}
11/11/08	18.8	20	30 (0.02)	7.9	0.74	53 (5.1)	2.05
12/01/09	17.9				0.88	89 (6.9)	1.27
24/02/09	19.4	22.3	7.6 (0.01)		0.64	22 (0.1)	1.91
13/03/09	19.7	20.4	3.5 (0.01)		0.60	5 (0.2)	1.59
NSW Trigger			2.2 (0.01)			1.9	
Median Other						2.4	
80th Other						6.6	

B Nadgee River - estuary

	Salinity (psu)	Temp (°C)	Turbidity (ntu)	pH	Entrance	Chlorophyll (µg.L^{-1})	Colour g m^{-1}
10/11/08	21.5	21.7	6	7.6	closed	2.9 (0.01)	1.49
12/01/09	31.0		3		open	3.7 (0.17)	0.71
24/02/09	32.68	23.2	3		open	4.3 (0.37)	1.43
16/03/09	31.48	23.4	1.8		closed	4.6	1.11

C Nadgee River – freshwater (TOWA 103)

	SpCond (µS.cm^{-1})	Temp (°C)	pH	DO (% Sat)	DO (mg.L^{-1})	Turbidity (ntu)	Colour g m^{-1}
12/11/2008	79.9	20.18	7.07	56	5.11	2.1	1.61

D Merrica River

	Salinity (psu)	Temp (°C)	Turbidity (ntu)	Chlorophyll a (µg. L^{-1})	Colour g m^{-1}
02/12/2009	28.1	18.4	0.7	4.22	3.45
13/01/2009	33.70	20.13	0.74	2.46	2.79
3/02/2009	34.06	24.82	0.48	4.60	1.29
25/02/2009	30.14	18.99	1.11	3.03	2.46
17/03/2009	34.27	19.00	0.64	3.89	

maximum of 22.3 and then decreased into autumn (Table 3 A). In November 2008, water temperature showed a slight variation between surface and bottom, ranging from 20 °C on the surface to18.2 °C on the bottom.

Turbidity was high in November 2008 (30 ntu) and decreased over the time of sampling (Table 3 A) and, in November 2008, was consistent from surface and bottom.

pH was only measured in November 2008 and was slightly basic (7.9) (Table 3 A). There was no vertical stratification of pH.

Dissolved colour, gilvin, was ranged between 2.05 and 1.27, but most data were near 2.

There was a strong depth stratification of dissolved oxygen which was at 100% saturation on the water surface, but had declined to 50 to 60% at the bottom. The logger data indicated that dissolved oxygen concentrations varied between 100 and 80% on a diurnal cycle from 11 November until 14 December 2008, after which time they slowly declined to be about 40% on 22 December 2008. This latter decline probably represents degradation of the membrane in the instrument.

Concentrations of dissolved inorganic nitrogen (oxidised nitrogen, ammonia) in November 2008 were uniformly small (Table 4), but concentrations of dissolved organic nitrogen and particulate nitrogen were relatively large. This resulted in large concentrations of total nutrients. A similar pattern was evident in January 2009. In February and March 2009, however, the concentrations of ammonia had increased by two orders of magnitude, without a concomitant increase in oxidised nitrogen. Dissolved organic nitrogen almost doubled and particulate nitrogen was reduced to about one third of previous concentrations. Phosphate concentrations were small and showed a slight peak in February 2009 (Table 4). Particulate phosphorus was the largest source of phosphorus and declined over the period of sampling. Concentrations of dissolved silica varied by two orders of magnitude over the sampling period (Table 4), being high (1340-1540) in November 08 and January 09 and lower in February (15) and March 09 (140).

Biota

Phyoplankton

Pelagic chlorophyll concentrations in the Lake were a very large 53 $\mu g.L^{-1}$ in November 2008 and 89 $\mu g.L^{-1}$ in January 2009, declining to 22 $\mu g.L^{-1}$ in February 2009 and 5 $\mu g.L^{-1}$ in March 2009 (Table 3 A). These concentrations indicate the presence of a very intense algal bloom and, indeed, the water colour was almost lime green in November 2008 and January 2009.

The phytoplankton assemblage in November 2008 was dominated by an intense bloom of very small (1 -2 μm) pico-plankton tentatively identified via light microscopy and pigment profiles as a monoculture of a cyanobacterium similar to *Synechocystis* . Samples from January 2009 were found to contain a mixture of some cyanobacteria (*Synechocystis*) and some diatoms, but were dominated by a Eustigmatophyte similar to *Nannochloropsis*. This alga is typically 2-4 μm in diameter. Samples from February 2009 were dominated by typical estuarine diatoms and dinoflagellates.

Zooplankton

Qualitative net samples indicated the presence of calanoid copepodites and larval polycheate worms. Quantitative samples indicated the presence of Rotifera (*Synchaeta* sp. 4.3 L^{-1}), copepod nauplii (31.5 L^{-1}), calanoid copepodites (7 L^{-1}), polychaetes (2.3 L^{-1}) and bryozoan cyphonuate larvae (1 L^{-1}).

Estuarine Macrophytes

Anecdotal information suggests strongly that Nadgee Lake had supported abundant aquatic macrophytes. Williams et al. (2006) identified a small bed of *Ruppia megacarpa* on the north-north west shore and more extensive beds on the southern shore (Fig 1). Extensive searching of the site on the north-west shore and of the wrack on the strand line on the entire northern shore did not locate sign of *Ruppia* sp. plants. All wrack was of terrestrial origin, primarily grasses, sedges and reeds which had been recently inundated. This tends to suggest that if there was any *Ruppia* in the lake at that time it was at very low abundances and did not form perennial beds. Coring and dragging of the lake floor in the central basin indicated that the sediment was coarse sand with a thick layer of finer dark grey organic material. There was a very small amount of a charophyte growing on the sediment, but no *Ruppia* plants or wrack were collected.

Fish assemblages

The limited sampling possible means that the fish sampled are unlikely to represent a comprehensive inventory of the fish species that inhabit the Lake. A total of 13 species were caught (Table 5), including sub-adult or adult specimens of common table fish such as luderick, Australian salmon, sea mullet, bream, garfish and flounder.

Table 4 Mean (SE), n=2, nitrogen, phosphorus and silica concentrations (µg.L-1) in surface water samples. NL – Nadgee Lake; NRL, NRU - Nadgee River Lower and Upper (respectively) refers to lower and upper estuary sites (Fig. 1); MR – Merrica River. * indicates derived value. NH4-N – ammonia; NOx-N – oxidised nitrogen; DIN – dissolved inorganic nitrogen; DON – dissolved organic nitrogen; PN – particulate nitrogen; TN – total nitrogen; PO4-P – phosphate; DOP – dissolved organic phosphorus; PP – particulate phosphorus; TP – total phosphorus. "Median Other" are median values for combined data from 4 other NSW minimally impacted lagoons (Termeil Lake, Meroo Lake, Brou Lake, Wallagoot Lake) sampled using the same methods between 2008 and 2010 (n = 60) and "80th Other" is the 80th percentile value calculated from the same data (DECCW unpublished data).

Date	Location	NH4-N	NOx-N	DIN*	DON*	PN*	TN	PO4-P	DOP*	PP*	TP	Silica
Nov 08	NL	6.9 (0.2)	1.6 (0.1)	8.5	931	2236	3176 (30)	1 (0.1)	7	98	106 (2.2)	1340 (43)
Jan 09	NL	6.4 (1.1)	1.7(0.4)	8.1	1074	1921	3003 (5)	1 (0.1)	7.7	78.3	87 (0.5)	1540 (1)
Feb 09	NL	451 (0.3)	8 (0.0)	459	1861	710	3031 (2)	2.2 0.3)	14.6	44	61 (0.5)	15 (1)
Mar 09	NL	436 (0.4)	5.3 (0.2)	441	1567	421	2428 (16)	1.4 (0.3)	13	27	41 (1)	140 (2)
Nov 08	NRL	4.4 (0.2)	1.4 (0.2)	5.8	191	55	252 (13)	0.3 (0.0)	3.6	6	10 (0.5)	390 (12)
Nov 08	NRU	11.6 (0.4)	4.6 (0.5)	16.2	203	72	291 (2)	0.8 (0.2)	4.4	10	15 (0.6)	133 (0.8)
Jan 09	NRU	2 (0.8)	1.2 (0.1)	3.2	146	49	196 (15)	0.3 (0.1)	3.7	7	11 (0.6)	495 (39)
Feb 09	NRU	6.9	1.3	8.2	176	119	296	1.0	6.1	17	24.5	407
Mar 09	NRU	8.8	3.6	12.5	203	50	257	0.9	5.5	12	18.3	289
Nov 08	MR	12 (6.7)	3.5 (2.4)	15.5	186	57	260 (36)	6.3 (1.8)	2.7	8.8	18 (2.8)	302 (52)
Feb 09	MR	5.4	2.8	8.2	188	37	234	2.4	3.2	5.6	11.2	140
	Median Other	10	2.9	12.5	711	56	903	1.2	10	9	22	324
	80th Other	94	7.8	101	1377	167	1620	2	12	19	30	825

Table 5 Fish Species from Nadgee Lake and River. Data are from all shots and methods combined.

		Lake		River	
		Total Number	Size Range (mm)	Total Number	Size Range (mm)
Acanthopagrus sp.	bream	6	104-205	33	56-168
Acentrogobius bifrenatus	bridled goby	1	42	1	68
Arripis trutta	eastern Australian salmon	4	268-325		
Afurcagobius tamarensis	Tamar River goby			2	53-56
Atherinosoma microstoma	small-mouthed hardyhead	302	41-58		
Centropogon australis	eastern fortescue	2	68-72		
Girella tricuspidata	luderick	1	318	6	295-360
Hyporhamphus regularis ardelio	eastern river garfish	13	143-186		
Leptatherina presbyteroides	silverfish	18	47-59		
Liza argentea	flat-tail mullet			13	147-295
Macquaria colonorum	estuary perch			7	325-363
Mugil cephalus	striped (sea) mullet	8	86-386	12	288-564
Myxus elongatus	sand mullet	15	150-169	43	122-280
Philypnodon grandiceps	flathead gudgeon	9	42-80		
Pomatomus saltatrix	tailor			1	215
Pseudocaranx dentex	silver (white) trevally			3	248-300
Pseudogobius olorum	blue-spot goby	4	38-44		
Pseudorhombus jenynsii	small-toothed flounder	2	194-217		
Synaptura nigra	black sole			1	170
Tetractenos glaber	smooth toadfish			5	50-110
Total Number of species: 20		No. spp. 13		No. spp. 12	

Sediment infauna

Benthic assemblages in Nadgee Lake contained groups of invertebrates typically found in estuarine habitats (Table 6). Polychaetes were numerically dominant, but diversity was evenly spread amongst the polychaetes, crustaceans and molluscan taxa. Within the polychaetes, three types of feeding modes were represented: mobile omnivores (Nereididae), burrowers (Orbiniidae) and filter feeders (Sabellidae), indicating a diverse food web in the existing assemblage, which probably depends on decaying plant material. No nematodes and relatively few oligochaetes were present, even in the fine fraction retained on 0.5 mm mesh.

Nadgee River Estuary

Observations

The river estuary was closed on 12 November 2008 and the beach berm was moderately wide (ca 15 m at narrowest point) and an estimated less than 0.5 m higher than the river surface. The river opened on 25 November 2008. Our observations are that in the period November 2008 – October 2010 the river opens 2 -3 times per year. The river was generally clear and when closed for a sufficient period (as on 08 November 2008), begins to flood up into the adjacent salt marsh and tea-tree wetlands.

Table 6 Mean (se) abundances and taxonomic richness of benthic invertebrates in Nadgee Lake. % overall abundance and summary statistics were estimated from pooled data for sites 1 and 2.

Taxonomic Group	Family	*Species*	Site 1 Mean per core n= 5	Site 2 Mean per core n= 2	% overall abundance
POLYCHAETES Class Polychaeta	Nereididae	*Simplisetia aequisetis*	4.4 (2.8)	5 (3)	17.88
	Orbiniidae	*Scoloplos normalis*	3.2 (1)	6.5 (0.5)	16.20
	Sabellidae	*Desdemona ornata*	2.6 (2.4)	0	7.26
CRUSTACEANS Order: Mysidacea	Mysidae		0.8 (0.4)	1.5 (1.5)	3.91
Order: Amphipoda	Aoridae		0.2 (0.2)	0	0.56
	Phoxocephalidae		4.2 (1.5)	9 (4.5)	21.79
	Synopiidae	*Synopia* sp.	0.8 (0.4)	0.5 (0.5)	2.79
MOLLUSCS Class Gastropoda	Hydrobiidae	*Ascorhis tasmanica*	2.4 (1.3)	7 (0.5)	14.53
Class Bivalva	Galeommatidae	*Arthritica helmsi*	0.4 (0.4)	2.5 (2)	3.91
	Tellinidae		0	0.5 (0.5)	0.56
	Veneridae		1.6 (1.6)	0	4.47
OTHER WORM PHYLA	Oligochaeta		1.6 (1.6)	0.5 (0.5)	5.03
	Platyhelminthes		0.2 (0.2)	0	0.56
OTHER PHYLA	Fish - Gobiidae		0.2 (0.2)	0	0.56

Summary statistics based on taxa	All Reps	% contribution	**Summary Statistics based on abundance**	All Reps	% contribution
Total number of taxa	14	100.00	Total number of individuals	179	100.00
Number of Polychaete taxa	3	21.43	Number of Polychaetes	74	41.34
Number of Crustacean taxa	4	28.57	Number of Crustaceans	52	29.05
Number of Mollusc taxa	4	28.57	Number of Molluscs	42	23.46
Number of Echinoderm taxa	0	0.00	Number of Echinoderms	0	0.00
Number of other worm taxa	2	14.29	Number of other worm phyla	10	5.59
Number of other taxa	1	7.14	Number of other phlya	1	0.56

Bathymetry

The estuary has relatively steep and confined banks for most of its length, meaning that maximum water depth is reached within a few metres of the bank. Banks above high tide are near-vertical for much of the length of the river. As a consequence, the surface area changes very little as the water depth increases after closure. Modal depth along the thalweg was 2.4 m, with the deepest areas 4.6 m, when closed. Low tide depths when open would be about 1 m less. The water surface area for the estuary was c.a. 18 ha, with an estimated volume of 0.43 ML, in the closed state.

Physical and chemical properties of the water

The salinity of the surface water in the upper Nadgee River estuary was strongly influenced by the entrance status. When the entrance had been closed for a while, salinity was 21 psu, but it rapidly rose to near seawater when open (Table 3 B). There was no evident stratification of the water column for salinity or DO (93 – 98% saturation) in November 2008.

Surface water temperature was slightly greater than Nadgee Lake and reached a maximum of 23.4°C in March 2009.

Turbidity was between 1.8 and 3 ntu when the river was open, but 6 ntu when closed (Table 3 B). In November 2008 there appeared to be slight increases in turbidity at the surface (6.4 ntu) and near the bottom (4.3 – 5.5 ntu) but most of the water column had low turbidity (1.7 – 1.9 ntu).

pH was only measured once, in November 2008. It was 7.6 and did not vary with water depth (Table 3 B). Gilvin colour ranged between 0.71 and 1.43 making it the least coloured of the estuaries (Table 3 B)

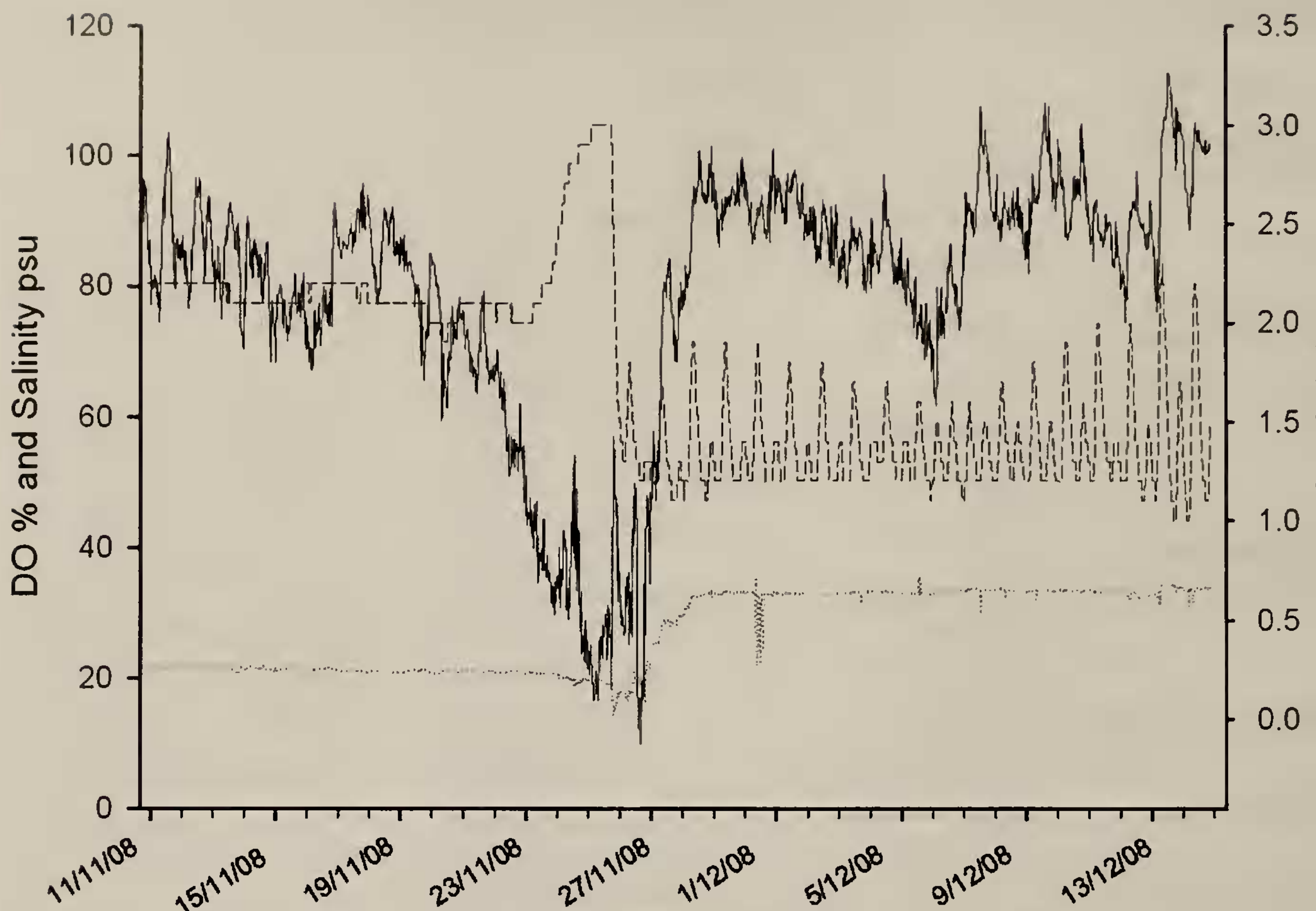

Figure 2 Salinity, depth and dissolved oxygen Nadgee River 11 November 2008 to 14 December 2008. Salinity (psu) – dotted line; depth (m) – dashed line and dissolved oxygen (% sat) solid line. Dates are at commencement of each day (00:00 hrs).

A water quality logger was deployed at a depth of 2.2 m in the River from 10 November until 14 December 2008 (Figure 2). Over the first 12 days salinity showed a slow decline from 21.8 to 20.7, depth was almost constant and dissolved oxygen saturation showed diurnal variation between 75% and 95%. Heavy rainfall in the catchment on about 23 November 2008 resulted in a rapid 1m increase in depth over 48 hours, followed by a 1.7 m drop. During this period, dissolved oxygen saturation dropped to 9%, but salinity at the probe only dropped by 4 psu – indicating stratification in the river. The salinity increased to 33 psu in three days and dissolved oxygen saturation returned to diurnal oscillations around 90% in the same time frame. Water depth began to show semi-diurnal tidal oscillations, with a neap range of 0.5m and a spring range of 1.2 m. It is clear from these data that the entrance opened late on 25 November following the rain on 23 and 24 November 2008 and near oceanic salinities established within 60 hours and remained for the duration of data collection.

Concentrations of dissolved inorganic nutrients (oxidised nitrogen, ammonia, phosphate) were small in November 2008 (Table 4). They were slightly greater in the upper parts of the estuary than the lower. Following opening, upper estuary concentrations in January 2009 were similar to lower estuary concentrations in November 2008, but by February and March 2009 the upper estuary concentrations had increased again to be similar to November 2008 (Table 4). These concentrations were similar to those initially measured at the Lake, but were two orders of magnitude smaller than the eventual ammonia concentrations at the lake. Concentrations of organic, particulate and total nutrient in the river were all about half those of the Lake (Table 4).

<u>Biota</u>

Phytoplankton

Mean pelagic chlorophyll concentrations in the River were 2.9, 2.6 $\mu g.L^{-1}$ (upper and lower, respectively) in Nov 08, 3.7 $\mu g.L^{-1}$ in January 09, 4.3 $\mu g.L^{-1}$ in February 09 and 4.6 $\mu g.L^{-1}$ in March 09 (Table 3 B).

Zooplankton

Net samples indicated the presence of calanoid copepodites, siphonophores, chaetognaths and microscopic jellyfish medusae.

Estuarine macrophytes

No submerged macrophytes (seagrass) were found in Nadgee River estuary, despite searches of the areas indicated as seagrass beds in Williams et al. (2006) and searches of wrack on the strandline. There were, however, considerable areas of saltmarsh on the shores of the estuary. The main species were *Melaleuca ericifolia*, *Juncus kraussii*, *Sarcocornia quinqueflora*, *Phragmites australis*, *Samolus repens*, *Leptinella longipes* and *Apium prostratum*. The limited observation possible confirmed the general locations of saltmarsh as shown in Williams et al. (2006) with the exception that the marsh area on the southern bank near the entrance is probably larger than indicated.

Fish assemblages

The limited sampling possible means that the fish sampled are unlikely to represent a comprehensive inventory of the fish species that inhabit the Lake. All data from each estuary have been combined into a single presentation. A total of 12 species were caught (Table 5), including sub-adult or adult specimens of common table fish such as bream, luderick, mullet (3 species), estuary perch, tailor and trevally.

Though only juvenile and sub-adult bream were caught in the nets, many large bream were observed at times along the banks.

Sediment infauna

Benthic assemblages in Nadgee River were only sampled in the marine bar near the river entrance. These samples contained groups typical of estuarine habitats, and were numerically and taxonomically dominated by crustacean amphipods (Table 7). The crustaceans were relatively diverse, with abundance distributed over five families, probably indicating diverse habitats and food pathways.

Nadgee River Freshwater Reaches

Waters at the Nadgee River ford were clear and slightly acidic, had low conductivity and moderate oxygenation (Table 3 C). The freshwaters were slightly more coloured than the estuary with a gilvin colour of 1.61, which represents only a low level of colouration.

The macro-invertebrate sampling showed a high diversity of families were present (Table 8). There were 22 taxa identified, compared with 19 in spring 1998. 5 taxa collected in 1998 were not found in 2008 and 8 taxa from 2008 were not found in 1998. The AUSRIVAS O/E score for 2008 was 0.91, putting it in Band A and indicating that the assemblage was close to reference.

Merrica River

Physical and chemical properties of the water

Surface salinity ranged between 28.1 and 34.3 psu (Table 3 D). The increase in salinity between 2 December 2008 and 13 January 2009 was a result of the river mouth opening. Turbidity was uniformly low (about 1 ntu). Merrica was the most coloured of the estuaries, ranging between 3.45 and 1.3, with three samples greater than 2.5.

Concentrations of dissolved inorganic nutrients were generally small (DIN 15.5 – 8.2 $\mu g.L^{-1}$, PO_4 6.3 – 2.4 $\mu g.L^{-1}$; Table 4), and were greater in November 2008 (when the estuary mouth was closed) than in February 2009 after the mouth had opened.

Biota

Chlorophyll concentrations ranged from 4.24 $\mu g.L^{-1}$ (when closed) to 2.54 $\mu g.L^{-1}$ when open.

DISCUSSION

The estuaries in the Nadgee Wilderness are subject to almost nil human intervention, around their shores, on their waters and in their catchments. Accordingly they represent conditions that are as near to natural as can be found in NSW. The physical, biological and chemical characteristics of the three estuaries studied were, however, quite different.

Nadgee River opened during the period of the data reported here and has opened a number of times since (DECCW unpublished data). The current opening frequency is 2-3 times per year. This is less than the frequency of "about 5 times per year" reported for the 1960s (NPWS 1975). Nadgee Lake, however, has not opened since November 2008 (DECCW unpublished data), despite several large storms. One storm in June 2010 led to overtopping of the berm by storm waves, but little significant outflow. NPWS (1975) report Nadgee Lake opened twice in 1969 and at those times Lake depths were about "4 feet" (1.2m). These relative opening frequencies agree with the inferences drawn from the ratios of catchment:area to lake surface area (Table 1) mentioned in the introduction. The estuary depths found here are similar (or perhaps a bit deeper) to those reported for 1969 (NPWS 1975), when the

Table 7 Mean (se) abundances and taxonomic richness of benthic invertebrates from Nadgee River. % overall abundance and summary statistics were estimated from pooled data for sites 1 and 2.

Taxonomic Group	Class	*Species*	Site 1 Mean per core n=2	Site 2 Mean per core n=3	% overall abundance
POLYCHAETES **Class Polychaeta**	Nereididae	*Australonereis ehlersi*	0.5 (0.5)	0	0.54
	Spionidae	*Dipolydora* sp.	0	0.7 (0.2)	1.08
CRUSTACEANS **Order: Mysidacea**	Mysidae		1 (1)	4.0 (1.6)	7.53
Order: Amphipoda	Aoridae		18.5 (17.5)	2.3 (0.7)	23.66
	Phoxocephalidae		6.5 (6.5)	11.7 (2.5)	25.81
	Platyischnopidae		1 (1)	7.7 (2.4)	13.44
	Synopiidae	*Synopia* sp.	3.5 (3.5)	4.3 (1.8)	10.75
	Urothoidae	*Urothoe* sp.	4.5 (1.5)	0.3 (0.2)	5.38
Order: Isopoda	Anthuridae	*Mesanthura* sp.	1 (0)	0.3 (0.2)	1.61
	Cirolanidae		0	0.3 (0.2)	0.54
Order: Cumacea	Diastylidae/ Gynodiastylidae		0.5 (0.5)	0.3 (0.2)	1.08
SubClass Copepoda	Copepoda		2.0 (1)	0.00	2.15
MOLLUSCS **Class Bivalva**	Galeommatidae		0.00	1.7 (0.5)	2.69
	Psammobiidae	*Soletellina alba*	0.50 (0.5)	0.7 (0.3)	1.61
	Veneridae		0.00	1.3 (0.7)	2.15

Summary statistics based on taxa	**Number**	**% contribution**	**Summary Statistics based on abundance**	**Number**	**% contribution**
Total number of taxa	15	100.00	Total number of individuals	186	100.00
Number of Polychaete taxa	2	13.33	Number of Polychaetes	3	1.61
Number of Crustacean taxa	10	66.67	Number of Crustaceans	171	91.94
Number of Mollusc taxa	3	20.00	Number of Molluscs	12	6.45
Number of Echinoderm taxa	0	0.00	Number of Echinoderms	0	0.00
Number of other worm taxa	0	0.00	Number of other worm phyla	0	0.00
Number of other taxa	0	0.00	Number of other phlya	0	0.00

Table 8 Abundances of macroinvertebrate taxa from Nadgee River (edge habitat) on 24 March 1998 and two collections on 12 November 2008.

Family	24 March 1998	12 November 2008	12 November 2008
Aeshnidae	1	0	0
Araneae	0	0	3
Atriplectididae	4	0	0
Atyidae	18	49	20
Calamoceratidae	7	1	1
Ceratopogonidae	0	2	2
Chironominae	99	4	7
Corixidae	1	0	1
Dytiscidae	3	0	3
Gerridae	7	0	0
Gomphidae	0	1	2
Gordiidae	1	2	1
Gripopterygidae	2	0	0
Gyrinidae	6	0	1
Hydracarina	13	9	9
Hydrophilidae	0	0	1
Leptoceridae	99	31	13
Leptophlebiidae	14	41	10
Megapodagrionidae	1	1	1
Odontoceridae	13	0	1
Oligochaeta	0	0	1
Philorheithridae	0	1	1
Scirtidae	2	4	1
Sisyridae	0	0	1
Sphaeriidae	0	0	4
Tanypodinae	8	1	5
Veliidae	2	0	0
Total Families	19	13	22

lake was "about 10 feet [3.3 m] when full" and the river was " 12 feet [4m] deep in holes". This indicates that there has not been any significant infilling in the last 40 years.

The presence of an intense algal bloom in the lake was not expected, nor was the extremely large concentrations of ammonia that followed the bloom. The extremely large chlorophyll concentrations and development of a monospecific bloom of cyanobacterial pico-plankton is without precedent (to the knowledge of the authors) in NSW. It appears that the cyanobacterium involved is a previously unknown species but the resources to confirm this were not available. The progression of the bloom from cyanobacteria to a eustigmatophyte and then diatoms was also of interest because this type of succession has not been previously reported in NSW estuaries

Scanes et al. (2007) showed that small levels of catchment disturbance do not always imply small concentrations of dissolved inorganic nutrients in estuarine receiving waters. In fact, they could find no relationship at all between magnitude of catchment disturbance and ambient nutrient concentrations. Those findings are confirmed in the data from Nadgee Wilderness, where ammonia concentrations ranged between 6 and 450 $\mu g.L^{-1}$ over a time span of 6 weeks, with no external inputs to the system. Data from other physically similar NSW estuaries (DECCW unpublished data) show that ammonia concentrations in some undisturbed estuaries can regularly reach 100 $\mu g.L^{-1}$. The default National Water Quality Management Strategy trigger value for ammonia is 15 $\mu g.L^{-1}$. The National Water Quality Management Strategy does, however, recommend that local "Trigger Values" for water quality variables be calculated by taking the 80th percentile value of data from reference estuaries. For ammonia in small south-coast lagoons (other than Nadgee estuaries), the 80th percentile value was 94 $\mu g.L^{-1}$, while the median value was 10 $\mu g.L^{-1}$ (Table 4). This indicates that while much of the time ammonia concentrations are small (about 10 $\mu g.L^{-1}$), at least 20% of the time they can be above 100 $\mu g.L^{-1}$, far greater than the default value. Ammonia concentrations in Nadgee Lake following the collapse of the algal bloom were, however, in excess of 400 $\mu g.L^{-1}$, which is much greater than seen anywhere else. We assume that these concentrations are a direct result of mineralisation of dead algal cells releasing ammonia to the water column. Ammonia concentrations in Nadgee River and Merrica River estuaries were much lower, only once exceeding 10 $\mu g.L^{-1}$. Batley and Simpson (2009) provided guidelines for toxicity of ammonia in estuarine systems. They recommend a toxicity trigger value of 160 $\mu g.L^{-1}$ for systems with high conservation values (this will protect an estimated 99% of species) and note that concentrations of 460 $\mu g.L^{-1}$ represent a low risk of acute or chronic toxic effects, protecting 95% of species. The (natural) ammonia concentrations in Nadgee are therefore at only low risk of causing toxic effects but are more than twice the high conservation criterion.

Concentrations of phosphorus in all estuaries were small, generally around the median value for south coast lagoons. The exception was particulate phosphorus in Nadgee Lake which was very high during the bloom – this is a consequence of the phosphorus in suspended algal cells.

All estuaries were coloured, but to varying extents. Colour was most intense in Merrica (mean 2.5), with a maxium of 3.45 when closed. This indicates colouration of waters from dissolved organic matter – strongly colour waters (e.g. Myall Lakes) have a gilvin colour of about 6.5, whilst clear estuarine water (e.g. Wallis Lakes) in NSW is about 1.2. Very clear waters (e.g. alpine lakes), have gilvin colour of 0.6 (Heinermann et al. 1990). Nadgee Lake was the next most coloured (mean 1.7) and Nadgee River the least coloured (mean 1.2). Nadgee River colour decreased markedly between the first and second samples, coinciding with the entrance opening.

The number of fish species caught in the Lake and River were about the same (13 and 12 respectively), but of the total species pool of 20, only 5 were common to both estuaries – bream, bridled goby, luderick and striped and sand mullet. Nine of the species caught in Nadgee Lake and 8 of those in Nadgee River were listed as abundant in seagrass by Jones and West (2005), who used a very similar seine in 6 south coast estuaries. All the others were noted as abundant in southern estuaries by Hutchins and Swainston (1986). It would be expected that the absence of seagrass or other submerged macrophytes would reduce the numbers of species likely to occur in the estuary (Bell and Westoby 1986, Scanes et al. 2010). Estuaries that remain closed for long periods also may have fewer species and reduced density of fish than those open more often (Loneragan and Potter 1990), though Jones and West (2005) found only weak support for this hypothesis. Given the relatively small fishing effort, both estuaries had reasonably diverse assemblages with means of 4.4 spp. per seine haul in the Lake and 3.3 spp. per seine haul in the River. This compares to approx. 6 spp. per seine haul in seagrass beds in the study of Jones and West (2005). Scanes et al (2010) sampled open estuaries with the same combined seine/mesh net techniques. They found a mean of 7 spp. per sample in samples over bare substrata, compared to a mean of 6 spp. per sample in both the Lake and River in this study. The fish assemblages of the Lake and Estuary can therefore be considered to be almost as diverse as those found in bare areas of open estuaries. About 60% of the species caught in the Nadgee estuaries are common in seagrass, but none of the species can be considered to be strongly attached to seagrass. Common strongly-associated seagrass species such as striped trumpeter, sygnathids and monocanthids were not found in either the Lake or Estuary. These data do not support the hypothesis that estuaries closed for long periods (e.g. Nadgee Lake) have depauperate fish assemblages. It should be noted, however, that the sampling effort in this study was relatively small, so it can be assumed that even more species would be found in the Nadgee estuaries with greater sampling effort.

The sediment invertebrate data indicated that, overall in the Lake, the number of animals per sample was low relative to other coastal estuarine habitats, however the assemblage was not considered depauperate. No nematodes and relatively few oligochaetes were present indicating that habitat disturbance or prevalent eutrophic conditions are not a regular occurrence in the Lake. In the River the crustaceans were the dominant fauna. They were relatively diverse, with abundance distributed over five families, probably indicating diverse habitats and food pathways. These samples were taken from the landward edge of the estuary bar-barrier and may be regularly disturbed when the barrier is broken open.

Although limited observations were made, the community structure of the zooplankton was relatively simple and reflected the typical estuarine conditions of Nadgee Lake and River. The dominance of the crustacean copepods in both Nadgee Lake and River are similar to that in other coastal estuarine habitats (Suthers et al. 2009).

Neither of the Nadgee estuaries had submerged macrophytes (seagrass or charophytes). This is not uncommon in intermittent estuaries, where the presence of seagrass or other macrophytes seems to be determined by factors other than human disturbance (West 1983). Some of the factors that are implicated are long-term recruitment success, salinity (which influences composition more than presence), opening frequency and stability of shallow substratum (Scanes and Coade in press, West 1983). NPWS (1975) noted that in the 1960s Nadgee Lake had dense beds of macrophytes but that in Nadgee River and Merrica River "macro-vegetation … is rare".

The Nadgee Wilderness estuaries are intact examples of estuaries that have had minimal to nil European intervention and therefore represent a very rare and important asset for future study. The few data that are now available suggest that there is, for some variables, considerable variation between the two estuaries. This is most likely due to the differences in ratios of catchment size to estuary volume, and hence propensity to open. The Nadgee Lake data indicate that some (or all) of our preconceptions about the chemical and algal dynamics of infrequently opened coastal lagoons may need to be re-examined. Fish appear to be diverse and abundant and assemblages do differ between the two estuaries.

Despite consistent reports and recordings of annual moulting aggregations of swans on Nadgee Lake from the previous 3 decades, swans (and any source of macrophyte or algal food) were absent from the Lake (and have remained absent until at least March 2011 – DECCW unpublished data). Perhaps this, along with the micro-algal blooms and anomalous ammonia concentrations, indicates that the ecology of Nadgee Lake has changed fundamentally and is moving into a new state. Perhaps this is how all NSW coastal lagoons functioned prior to large-scale land clearing released tonnes of sediment into them? These questions will only be answered by continued research into the ecology, aquatic chemistry and biogeochemistry of these pristine systems.

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